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Abstract

Heat Transfer Characteristics of Helical Tube Bundles as used in Steam Generators of Gas-cooled Reactors

P.V. Gilli
Waagner-Biro A.G., Vienna

Helical tube bundles are being used for steam generators of gas-cooled reactors of the natural uranium, CO_2-cooled and the high temperature helium-cooled type. The steam generators (primary heat exchangers) of the U.K.A.E.A. High Temperature Reactor Project Dragon that have been designed and manufactured by the Waagner-Biro A.G. in co-operation with the Dragon Project are of particular interest since they are compact units of extremely high power density. Heat transferred per unit tube bundle volume amounts to 12.0 MWth/m^3, per internal casing volume to 9.02 MWth/m^3. Steam rate per unit volume is 23,000 kg/h,m^3 and 5,770 kg/h,m^3, respectively. These values compare favourably with other existing conventional or nuclear steam generators with gases as heat transfer media.

The high density of heat transfer and steam production of the Dragon boilers is due, amongst other reasons, to the somewhat novel compact tube arrangement. Each one of the six Dragon steam generator units consists of seven concentric cylinders of helical evaporator tubes in a multistart arrangement with numbers of starts increasing with helix diameter. Hence the angles of inclination as well as the heated lengths of the tubes are equal despite the large diameter differences of the seven helices. Thus flow resistance and mass flow per tube are equal.

Little published data is available on the heat transfer characteristics of bundles of plain helically-wound tubes in general and no data on the effects of the continuous change between in-line and staggered tube arrangement - which is a characteristic of the

design described - in particular. An experimental programme dealing with gas-side as well as steam/water-side heat transfer was therefore put in hand and is reported upon.

Gas-side heat transfer experiments were carried out under participation of Dragon Project. Results can be described in the range above $Re_f = 2000$ by the following formula:

$$St_f = 0.37\ Re_f^{-0.4}\ Pr_f^{-0.667}$$

where the subscript f refers to gas properties evaluated at the mean film temperature taken at the logarithmic mean of the heat transfer area and where the mass velocity term in the Reynolds Number refers to a nominal free gas flow area taken as the arithmetic mean between free area of in-line arrangement and free area of staggered tube arrangement based on transversal openings. A transition of flow regimes is apparent below $Re_f = 2000$ but no instabilities or oscillations were observed.

Due to the high heat flux in the steam generators of the Dragon reactor experiment (maximum values are of the order of 500 kW/m^2), steam/water side heat transfer is of special interest. Actual values of the boiling heat transfer coefficient were measured over the length and around the perimeter of the test tubes. For some cases, "burn-out" conditions were determined.